# 5

# Nuclear Proliferation

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## 1. Introduction

Early nuclear energy system designs grew out of programs to develop nuclear weapons, and accordingly these systems were optimized to produce weapons usable material. As the nuclear industry matured and the use of nuclear power spread, safety, cost, environmental impact and waste management considerations shaped nuclear energy system designs that were deployed for the purpose of producing electricity. A multi-faceted international nonproliferation regime comprised of treaty commitments and obligations, verification mechanisms, export controls, and diplomatic strategies intended to dissuade States from proliferating has grown (Figure 1). Likewise, measures to prevent theft of nuclear materials by subnational groups have been implemented at both the national and international levels. There has been continuing interest in developing nuclear technologies that would permit the peaceful use of nuclear power without an associated proliferation of nuclear weapons capability. The term "proliferation resistant" was coined to describe technologies that are not suitable for the production of weapons usable material.

Despite this interest in "proliferation resistant technologies," the reality remains that a truly proliferation-proof nuclear energy system has yet to be discovered. A fuller understanding of the nature of nuclear proliferation would suggest that motivation, underlying political-military ambitions, in some cases domestic political imperatives, are key drivers for proliferation or for decisions not to pursue nuclear weapons development. There is no technological "silver bullet" that will solve the proliferation challenge. Even for technologies that are said to be more difficult to misuse for proliferation purposes, one must recognize that the international transfer of such technology can impart to the recipient technical capabilities and know-how that can be put to use in facilities that could be used to support a nuclear weapons program.

A more productive course of action would be to consider how a particular technology or facility design might lend itself to more effective and efficient forms of international verification by the International Atomic Energy Agency. Beginning early in the 1950s, international safeguards agreements and principles were put in place to make certain that as the use of nuclear power spread it would be used for peaceful purposes only, and if a State were to misuse these technologies it would be detectable so that the international community could take timely action. The more difficult and detectable it was to use a system to make nuclear weapons usable material, the better.

As discussed below, the notion of "proliferation resistance" in this context is more relative, that is, how one system might compare to another. Results of proliferation resistance studies should not be construed as implying that a particular system is proliferation-proof, nor that features claimed to make a system more proliferation resistant provide a rationale for relaxing: 1) international safeguards for such systems; 2) controls on the export of such systems and related technologies; or 3) the nonproliferation credentials and commitments of the recipient of such technology transfers.

Fig. 1. International safeguards agreements

Nuclear energy system designers and engineers must understand not only how to design and build their systems to make them safe and secure, but also easy to safeguard. In this chapter, we will show how proliferation resistance has been studied, what can be learned from these studies, and how the results can used in the international community. As already stated, the problem of nuclear proliferation is multi-faceted, with a long and complicated history, and for purposes of this chapter we will focus only on the concept of proliferation resistance.

## 2. Proliferation resistance

The generally accepted definition for *proliferation resistance* is:
*"… that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material or misuse of technology by States in order to acquire nuclear weapons or other nuclear explosive devices. The degree of proliferation resistance results from a combination of, inter alia; technical design features, operational modalities, institutional arrangements and safeguards measures. Intrinsic proliferation resistance features are those features that result from the technical design of nuclear energy systems, including those that facilitate the implementation of extrinsic measures. Extrinsic proliferation resistance measures are those measures that result from States' decisions and undertakings related to nuclear energy systems."* (IAEA-STR-332, 2002)

This definition makes clear that proliferation resistance should be considered a function of the *intrinsic* technical features (facility design and operation) and *extrinsic* properties (implementation of international agreements and safeguards) of a nuclear energy system. The degree of effectiveness of these properties is used to determine a nuclear energy system's proliferation resistance.

Studies of nuclear proliferation can be broadly separated into two distinct categories, as follows:

- *State-level* proliferation studies (e.g., Meyer 1984; Singh & Way 2004; Li et al. 2009, etc.) examine the implications and consequences of State motivations, resources (technical, human, and financial), geostrategic or regional rivalries, and international agreements. Using this information, analysts assess the likelihood that a State will proliferate or attempt to do so.
- *Technical* proliferation studies address elements of Nuclear Energy Systems (NES), focusing on their possible contributions to a nuclear weapons program. Technical studies can range from evaluating an individual facility or unit to examining all elements of a fuel cycle.

This chapter focuses on technical proliferation resistance studies, which can be used to:

- evaluate characteristics of proposed nuclear energy systems that are intended to impede the diversion or undeclared production of nuclear material or the misuse of technology,
- evaluate the vulnerability of proposed NES design and operational features from a proliferation resistance point of view,
- evaluate the applicability and effectiveness of international safeguards measures,
- provide a basis for improving both facility intrinsic features (design options) and extrinsic measures (safeguards) to achieve an appropriate balance, and
- communicate proliferation resistance strengths and weaknesses of the NES to decision makers in a transparent, understandable and meaningful way. (Zentner, et al., 2009)

## 3. Proliferation risk

Although the terms "proliferation resistance" and "proliferation risk" are sometimes used interchangeably, they are not synonymous. Technically, risk can be defined (Kaplan & Garrick, 1981) in terms of a risk "triplet": *1) What can go wrong? 2) How likely is it? 3) What are the consequences?* For proliferation risk, technical proliferation resistance studies answer the first and the third questions, but answering the second—the *likelihood* of the deliberate act of proliferation—is a difficult calculation most suited to State level proliferation studies as described above.

Accordingly, proliferation resistance should be considered a component of proliferation risk, and proliferation resistance studies may be useful to identify means of addressing elements of that risk. The concept of proliferation risk includes much broader political considerations than proliferation resistance, and will not be further addressed here.

## 4. Physical protection

It is important to understand the difference between the concepts of Proliferation Resistance and Physical Protection. *Physical protection* is defined as "that characteristic of an NES that impedes the theft of materials suitable for nuclear explosives or radiation dispersal devices

(RDDs) and the sabotage of facilities and transportation by sub-national entities and other non-Host State adversaries.

The objective of a physical protection system is to minimize the susceptibility to and opportunity for unauthorized removal of nuclear material in use, storage or transport and of sabotage of nuclear material and nuclear facilities. The effectiveness of the system is demonstrated by its capability to prevent the successful execution of a malicious act and to prevent and/or mitigate radiological consequences thereof.

Physical protection concerns are not unique to the nuclear industry. Although what is to be protected; consequences of a successful attack; and approaches for detecting, delaying, and responding to an attack may differ, the same basic principles are applied to protect any important facility against sabotage or theft, whether it is an NES, an oil refinery, a communications center, or a military site (Bari, 2009). Accordingly Physical Protection will not be further addressed in this chapter.

## 5. Studying proliferation resistance

A number of distinct procedures for the study of proliferation resistance exist. Four representative methodologies (TOPS[1], INPRO[2], SAPRA[3], and GEN IV PR&PP WG[4]) are described below. All use the standard definition of proliferation resistance, "… *that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material or misuse of technology by States in order to acquire nuclear weapons or other nuclear explosive device…"*, but take distinctly different approaches.

They can be broadly separated into two classes: multi-attribute utility analyses (MAUA) and pathway analyses. In the first class (TOPS, INPRO, and SAPRA) a set of attributes (i.e., material and technical barriers to proliferation) are identified and relevant values are established for measuring the relevant importance or effectiveness of each barrier against a particular proliferation threat. In the second class (GEN IV PR&PP WG) possible proliferation pathways are postulated involving the diversion of weapons usable material or misuse of technology to produce such material. For each pathway, acquisition scenarios are identified and analyzed, and the resulting outcomes are compared using specified sets of proliferation resistance measures.

### 5.1 Technological Opportunities to Increase the Proliferation Resistance of Global Civilian Nuclear Power Systems (TOPS)

The TOPS Task Force [5] was established in 1999 to "identify near and long-term technical opportunities to increase the proliferation resistance of global civilian nuclear power systems and to recommend specific areas of research that should be pursued to further these goals" (TOPS, 2001). After reviewing several proposed approaches, a MAUA methodology was developed that identifies a set of material and technical attributes considered barriers to proliferation, with relevant importance values. *Material barriers* are properties that affect the

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[1] TOPS: *Technological Opportunities to Increase the Proliferation Resistance of Global Civilian Nuclear Power Systems*

[2] INPRO: *International Project on Innovative Nuclear Reactors and Fuel Cycles* (IAEA)

[3] SAPRA: *Simplified Approach for Proliferation Resistance Assessment of Nuclear Systems*

[4] GEN IV PR&PP WG: *Generation IV Proliferation Resistance and Physical Protection Working Group*

[5] Created by the U.S. Department of Energy (DOE) Office of Nuclear Energy, Science, and Technology and DOE's Nuclear Energy Research Advisory Committee (NERAC)

desirability or attractiveness of the material as an explosive. *Technical barriers* are those aspects that make it difficult to gain access to materials and/or to use or misuse facilities to obtain weapons-usable materials (Table 1).

▨ Barriers Considered in each method

| Barrier Descriptions | | | **TOPS** | **SAPRA** | | | | Note |
|---|---|---|---|---|---|---|---|---|
| | | | | Diversion | Transport | Transform | Weapon fabricate | |
| **Material** | **Isotopic** | Critical Mass | ▨ | | | | | 1 |
| | | Isotopic Enrichment | ▨ | | | ▨ | | 2 |
| | | Spontaneous Neutron Generation | ▨ | | | | ▨ | |
| | | Heat Generation Rate | ▨ | | | | ▨ | |
| | | Radiation | ▨ | | | | ▨ | |
| | Dangerousness (other than irradiation) | | | ▨ | | | | |
| | Chemical | | ▨ | | | ▨ | | |
| | Radiological (other than the material) | | ▨ | ▨ | ▨ | | | |
| | Mass and bulk | | ▨ | ▨ | ▨ | | | |
| | Physical form | | | ▨ | | | | |
| | Detectability | | ▨ | ▨ | ▨ | | | |
| **Technical** | Facility unattractiveness | | ▨ | | | | | 3 |
| | Facility accessibility | | ▨ | ▨ | | | | |
| | Available mass | | ▨ | ▨ | | | | |
| | Diversion detectability | | ▨ | ▨ | | | | |
| | Skill, expertise, knowledge | | ▨ | | | ▨ | ▨ | |
| | Time | | ▨ | | | ▨ | ▨ | |
| | Technical difficulty | | | ▨ | | | | |
| | Collusion level | | | ▨ | | | | |
| | Construction detectability | | | | | ▨ | | |
| | Signature of installation | | | | | ▨ | | |
| **Extrinsic** | Safeguards | | ▨ | ▨ | | | | |
| | Access/control/security | | ▨ | ▨ | ▨ | | | |
| | Location/distance (for transport phase) | | ▨ | | ▨ | | | |

**Notes:**

1 - in SAPRA, this barrier is implicitly included in "Mass and Bulk" barrier

2- Isotopic barrier plays a role only when enrichment is inescapable to obtained direct weapons usable material

3 - In SAPRA, this barrier is implicitly included in other technical barriers linked to the diversion phase, in particular the "technical difficulty" and accessibility" barriers

Table 1. Comparison of TOPS and SAPRA barriers (Greneche et al., 2007)

Examples of material barriers used in the original TOPS procedure included material isotopic, radiological, and chemical properties, in addition to mass or bulk. Technical barriers included attractiveness of the facility to a potential weapons program, difficulty of facility access, detectability of proliferator actions, and necessary skills and time needed for the proliferator's actions.

As the use of the TOPS methodology has matured, a variety of approaches has been developed to determine barrier values. For example, in one proliferation resistance study using the TOPS approach (Skutnik et al., 2009), barrier values were developed using a "fuzzy logic" based attributed analysis approach. This technique was intended to overcome the challenges of subjectivity inherent in development of the barrier values. The resulting model was tested by evaluating several reprocessing technologies, and the results were found to generally agree with more structured PR studies.

The TOPS approach forms the basis for a number of advanced assessment methodologies, two of which (INPRO and SAPRA) are described in more detail below.

### 5.2 Simplified Approach for Proliferation Resistance Assessment of Nuclear Systems (SAPRA)

In 2002, a French nuclear industry working group was formed to select and develop a methodology for assessing the proliferation resistance of nuclear energy systems. The result was a methodology called the *Simplified Approach for Proliferation Resistance Assessment of Nuclear Systems* (SAPRA). SAPRA (Greneche et al., 2007) is an evolutionary approach based on the TOPS methodology, with a number of modifications, additions, and improvements. Table 1 compares the two approaches.

SAPRA separates proliferation into four phases: diversion, transport, transformation, and nuclear weapon fabrication. At each phase, intrinsic and extrinsic barriers to proliferation are identified and scored based on the perceived robustness of the barrier. SAPRA addressed the complete fuel cycle. A panel of experts was assembled to determine the values to be assigned to each of the barriers. The values were then added together to give an aggregate "Proliferation Resistance Index." Using these results the strengths and weaknesses of the various nuclear energy systems studied were identified. SAPRA is unique among most proliferation resistance assessment approaches in that it explicitly includes theft by a State as a possible proliferation threat.

### 5.3 Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems – Proliferation Resistance (INPRO)

Beginning in 2002, the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) developed a proliferation resistance assessment methodology that is primarily based on a multi-attribute utility analysis approach. The INPRO proliferation resistance approach identifies one *Basic Principle of Proliferation Resistance* with five *User Requirements* for meeting this Principle, along with seventeen indicators with specific criteria and acceptance limits (IAEA, 2007).

The Proliferation Resistance Basic Principle is: "*Proliferation resistance intrinsic features and extrinsic measures shall be implemented throughout the full life cycle for an INS to help ensure that INSs will continue to be an unattractive means to acquire fissile material for a nuclear weapons program. Both intrinsic features and extrinsic measures are essential, and neither shall be considered sufficient by itself.*"

The five Proliferation Resistance User Requirements are:

1. States' commitments, obligations and policies regarding nonproliferation and its implementation should be adequate to fulfil international non-proliferation standards.
2. The attractiveness of nuclear material and nuclear technology in an INS for a nuclear weapons program should be low.
3. Any diversion of nuclear material should be reasonably difficult and detectable.
4. Innovative nuclear energy systems should incorporate multiple proliferation resistance features and measures.
5. The combination of intrinsic features and extrinsic measures, compatible with other design considerations, should be optimized in the design/engineering phase to provide cost-efficient proliferation resistance.

Table 2 (IAEA, 2007) shows User Requirement 3 including the description of the User Requirement, related criteria, indicators, and acceptance limits.

Several studies have been performed to demonstrate the use of the INPRO methodology. An important example is the "INPRO Collaborative Project PRADA: *Proliferation Resistance: Acquisition/Diversion Pathway Analysis*" (Chang & Ko, 2010). In this study of the proposed South Korean DUPIC[6] fuel cycle User Requirements 3 and 4 were evaluated using a modification of the PR&PP pathway analysis methodology (section 5.4). The PRADA study concludes that a multiplicity of barriers is not sufficient to ensure robust proliferation resistance; rather robustness is not a result of the number of barriers or of their individual characteristics but is an integrated function of the whole system.

### 5.4 Generation IV International Forum Proliferation Resistance and Physical Protection Evaluation Methodology (GEN IV PR&PP WG)

The Generation IV International Forum[7] (GIF) formed a working group in December 2002 to develop a method for studying proliferation resistance and physical protection of advanced NES to support the proliferation related technology goal of Generation IV (GIF002-00, 2002; PR&PP, 2006) Nuclear Energy Systems (NES): *"Generation IV NESs will increase the assurance that they are a very unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism."*

After exploring several options, the working group developed a methodology using a pathway analysis approach. The methodology separates pathways into three stages: acquisition, processing, and weaponization. *Weaponization* is normally not further evaluated in these GIF studies. For a proposed NES design, proliferation challenges (or threats) are identified, the NES response to these challenges is analyzed, and outcomes are assessed as a set of proliferation resistance measures for each pathway (Figure 2).

The measures determine: 1) the difficulty of the approach; 2) how long it will take to accomplish the goal; 3) how much it will cost to achieve; 4) how much the safeguards system for the NES will cost; 5) how likely it is that actions in the pathway will be detected; and 6) the material of concern

While developing the methodology, members of the working group performed a number of studies to demonstrate and improve the approach. A PR evaluation of a proposed nuclear energy system consisting of four liquid metal reactors and co-located reprocessing and fuel

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[6] DUPIC (Direct Use of PWR spent fuel In CANDU reactors)

[7] The Generation IV International Forum is "*a cooperative international endeavor organized to carry out the research and development (R&D) needed to establish the feasibility and performance capabilities of the next generation nuclear energy systems.* " (GIF, 2000)

production facilities (PR&PP, 2009), showed that a study performed early in the conceptual design phase of an NES can provide information useful for ensuring an optimal safeguards system concept and provide a basis for detailed systems design. A PR evaluation (Whitlock, 2010) of an advanced CANDU reactor design (*ACR-1000*) provided useful information to the facility design team and resulted in changes that improved facility safeguards without impacting other design requirements. In another study (Zentner, et al. 2010) a suite of four reactors was evaluated against a common set of proliferation threats, and areas where safeguards approaches and technology can be improved through the use of safeguards-by-design studies were identified.

| **Basic Principle BP:** Proliferation resistance intrinsic features and extrinsic measures shall be implemented throughout the full life cycle for innovative nuclear energy systems to help ensure that INSs will continue to be an unattractive means to acquire fissile material for a nuclear weapons program. Both intrinsic features and extrinsic measures are essential, and neither shall be considered sufficient by itself. | | |
|---|---|---|
| **User Requirements (UR)** | **Criteria (CR)** | |
| | **Indicator(IN)** | **Acceptance Limits (AL)** |
| **UR3 Difficulty and detectability of diversion:** The diversion of nuclear material (NM) should be reasonably difficult and detectable. Diversion includes the use of an INS facility for the production or processing of undeclared material. | **CR3.1** quality of measurement | |
| | **IN3.1:** Accountability. | **AL3.1:** Based on expert judgment equal or better than existing designs, meeting international state of practice. |
| | **CR3.2** C/S measures and monitoring | |
| | **IN3.2:** Amenability for C/S measures and monitoring. | **AL3.2:** Based on expert judgment equal or better than existing designs, meeting international best practice. |
| | **CR3.3** detectability of NM | |
| | **IN3.3:** Detectability of NM. | **AL3.3:** Based on expert judgment equal or better than existing facilities. |
| | **CR3.4** facility process | |
| | **IN3.4:** Difficulty to modify process. | **AL3.4:** Based on expert judgment equal or better than existing designs, meeting international best practice. |
| | **CR3.5** facility design | |
| | **IN3.5:** Difficulty to modify facility design. | **AL3.5 = AL3.4** |
| | **CR3.6** facility misuse | |
| | **IN3.6:** detectability to misuse technology or facilities. | **AL3.6 = AL3.4** |

Table 2. INPRO User Requirement 3, Difficulty and detectability of diversion

The results of these studies establish that the methodology can usefully frame the evaluation of the proliferation resistance of a variety of nuclear fuel cycles. It can also provide insight into the effectiveness of integrated safeguards, and support the development of improved safeguards to support new NES designs.

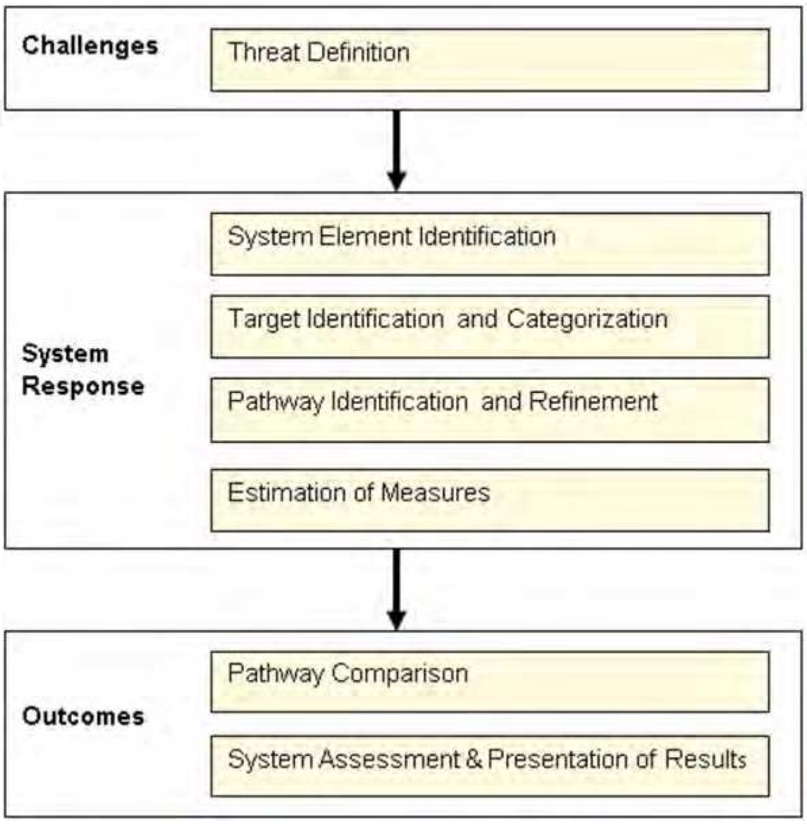

Fig. 2. Framework for the PR&PP Evaluation Methodology

## 6. Usefulness of proliferation resistance studies

The results of proliferation resistance studies can be used by decision-makers at all levels:

- Government officials, including Ministry of Energy, Ministry of Foreign Affairs and legislative officials responsible for program approvals and funding appropriations
- National licensing and regulatory authorities; export control authorities for State exports, imports and indigenous development
- IAEA safeguards authorities and other safeguards inspectorates
- Industrial designers/producers/vendors
- Utility owners and operators (Pomeroy, et al., 2008)

Decisions made by these authorities (Table 3) will set priorities for the activities of the nuclear energy system designers and can help determine the types of technologies and designs to pursue when investing in or building new civil nuclear facilities. Information provided by proliferation resistance assessments, properly used, can: 1) identify potential safeguards issues early in the design process; 2) provide a framework for the selection of design approaches that could make safeguards at the facility more efficient and effective; 3) identify design innovations that could either raise new safeguards issues or lessen cost impacts on the IAEA or the facility operator; and 4) enable the designer to focus on whether to address new safeguards issues with design modifications that eliminate the issue or with enhanced safeguards measures (Wonder & Hockert, 2011).

| **Potential Users of a Proliferation Resistance Assessment and Evaluation Methodology** | **Illustrative Uses of Proliferation Resistance Information** |
|---|---|
| Government officials, including Energy Ministry officials, Foreign Ministry Officials and Legislative officials responsible for program approvals and funding appropriations | 1. Ensuring provision of sustainable energy supply from safe, secure, economic and proliferation resistant sources.<br>2. Basing nuclear export control decisions on well-understood and assessed proliferation threats |
| National licensing and regulatory authorities, and export control authorities, for State exports, State imports and indigenous development | 1. Developing guidance on and validation of effective and efficient implementation of proliferation resistance/safeguards requirements in design and operation<br>2. Providing basis for cooperation with regional and international safeguards authorities |
| IAEA safeguards authorities and other safeguards inspectorates | 1. Providing understanding of the role of safeguards measures in proliferation resistance<br>2. Ensuring that facility design and operation facilitate the implementation of safeguards |
| Industrial designers/producers/vendors | 1. Employing usable guidance for effective and efficient implementation of proliferation resistance/safeguards requirements in design and operation<br>2. Ensuring that there are transparent acceptance procedures with assessable cost impacts |
| Utility owners and operators | 1. Enhancing public acceptance of nuclear energy production<br>2. Providing transparent means for demonstrating that perceived threats are adequately controlled<br>3. Optimizing extrinsic and intrinsic proliferation resistance measures with facility safety, operations, and cost |

Table 3. Users and Uses of Proliferation Resistance Information (Pomeroy, et al., 2008)

The following section describes how the results of proliferation resistance studies can be used, including discussions concerning nuclear material evaluation, facility safeguardability, and the implementation of safeguards by design.

### 6.1 Nuclear material evaluations

As more work in this area is performed, a number of lessons have been learned and some potential misconceptions have been identified. Experts generally agree that the attractiveness of the nuclear material and nuclear technology in an innovative nuclear system for use in a nuclear weapons program should be low. An important issue under current investigation is the concept of a “proliferation proof” material. Some have proposed that a material could be identified or developed that would be difficult—if not impossible—to use as a weapon or nuclear explosive device because of the material’s isotopic content, its intrinsic radiation field, heat load, or other features. Such material would have minimal safeguards requirements.

A team of specialists from the United States focused on material attractiveness issues from the standpoint of potential usability in a nuclear explosive device. Their studies reviewed a variety of materials associated with existing and proposed reprocessing schemes and nuclear fuel cycles. The research concluded that there are no “silver bullets” in conventional or advanced fuel cycle reprocessing schemes (e.g.; PUREX, UREX, COEX, and pyro-processing). All products from such schemes are potentially attractive for use in a nuclear weapon or nuclear explosive device (Bathke, et al., 2009).

The results of these studies support the assertion that relying on intrinsic features in a nuclear fuel cycle will not be sufficient to ensure that proliferation resistance goals will be met. Effective safeguards are of primary importance to the proliferation resistance of a nuclear energy system, and care must be taken not to construe proliferation resistance as being largely a function of intrinsic measures or as an absolute characteristic in the sense of a nuclear energy system being *proliferation proof*. Consequently, extrinsic features such as international safeguards and other institutional measures such as controls on the export of sensitive enrichment and reprocessing technologies remain essential and cannot be lessened. Rather, it is important to make these measures more effective and cost efficient by improving the “safeguardability” of an NES.

### 6.2 Safeguardability

The fundamental objective of international safeguards is to detect in a timely manner: 1) the diversion of significant quantities of nuclear material from peaceful to non-peaceful uses, and/or 2) possible misuse of nuclear facilities for undeclared purposes. How well and how efficiently an NES meets this objective is defined as its *safeguardability*. Safeguardability can be understood as the extent to which the facility design readily accommodates and facilitates effective and cost-efficient safeguards, that is, effectively integrating a nuclear facility design’s technical features with required safeguards measures.

An important use of the results of proliferation resistance studies is to evaluate and if necessary improve the safeguardability (Bjornard et al., 2009) of an NES by: 1) identifying, evaluating, and optimizing intrinsic barriers in the system design; 2) reviewing and evaluating safeguards measures for cost and effectiveness; and 3) ensuring that safeguards goals can be met. Figure 3 outlines this process.

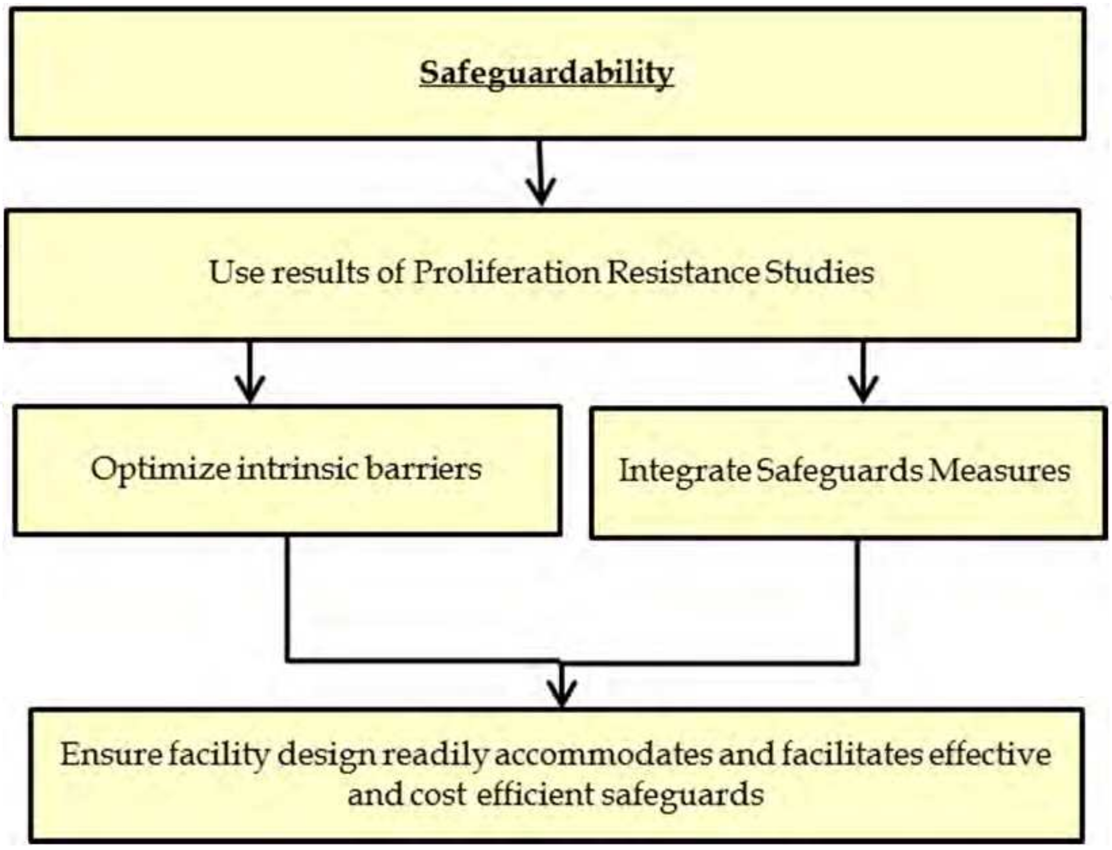

Fig. 3. Elements of safeguardability

Updating and strengthening a structured approach for accomplishing "Safeguards-by-Design" (IAEA, 2009) to help improve the safeguardability of NES facilities is receiving substantial international attention, elements of this activity are discussed further below.

### 6.3 Safeguards-by-Design

The IAEA has described the Safeguards by Design (SBD) concept as an approach in which "international safeguards are fully integrated into the design process of a new nuclear facility from the initial planning through design, construction, operation, and decommissioning" (IAEA, 2009). SBD has taken on a new importance in light of the expected "Nuclear Renaissance" and the requisite expansion of the global reactor fleet with an increased number and variety of reactors and fuel cycles under safeguards. As these new nuclear energy systems are being planned and constructed, it is clear that the IAEA must find ways to optimize its verification activities amidst continuing constraints on the financial and human resources available to it for safeguards. Consequently, the nuclear industry is beginning to address the problem of how it can facilitate the application of IAEA safeguards in a manner that provides benefits to both the IAEA and the facility operator. SBD is intended to help solve this issue by developing a structured approach for designing and incorporating safeguards features into new civil nuclear facilities at the earliest stages in the design process, and designing the facility in such a way that it more readily lends itself to being safeguarded.

Broadly speaking, this effort would involve using safeguardability assessment tools: 1) to aid designers in identifying potential safeguards issues early in the design process; 2) to provide them with a framework for the selection of facility-specific SBD best practices and lessons learned; and 3) to help them anticipate where innovations in their designs might pose new safeguards issues that might be addressed through changes in the design, or enhancements of accepted safeguards approaches in a manner likely to meet IAEA safeguards requirements while mitigating cost impacts on both IAEA and the facility operator (Wonder & Hockert, 2011). This approach, as laid out in Figure 4, parallels the PR&PP assessment methodology.

Stakeholders responsible for developing and incorporating SBD in the design and construction of new nuclear facilities include those responsible for the design, approval, construction, oversight, operation, and safeguarding of a nuclear facility. These stakeholders include:

- The IAEA
- Owners/operators
- Designers/builders
- Regional or State Systems of Accounting and Control (R/SSAC), and
- Equipment providers.

The future application and development of the concept of SBD is ongoing.

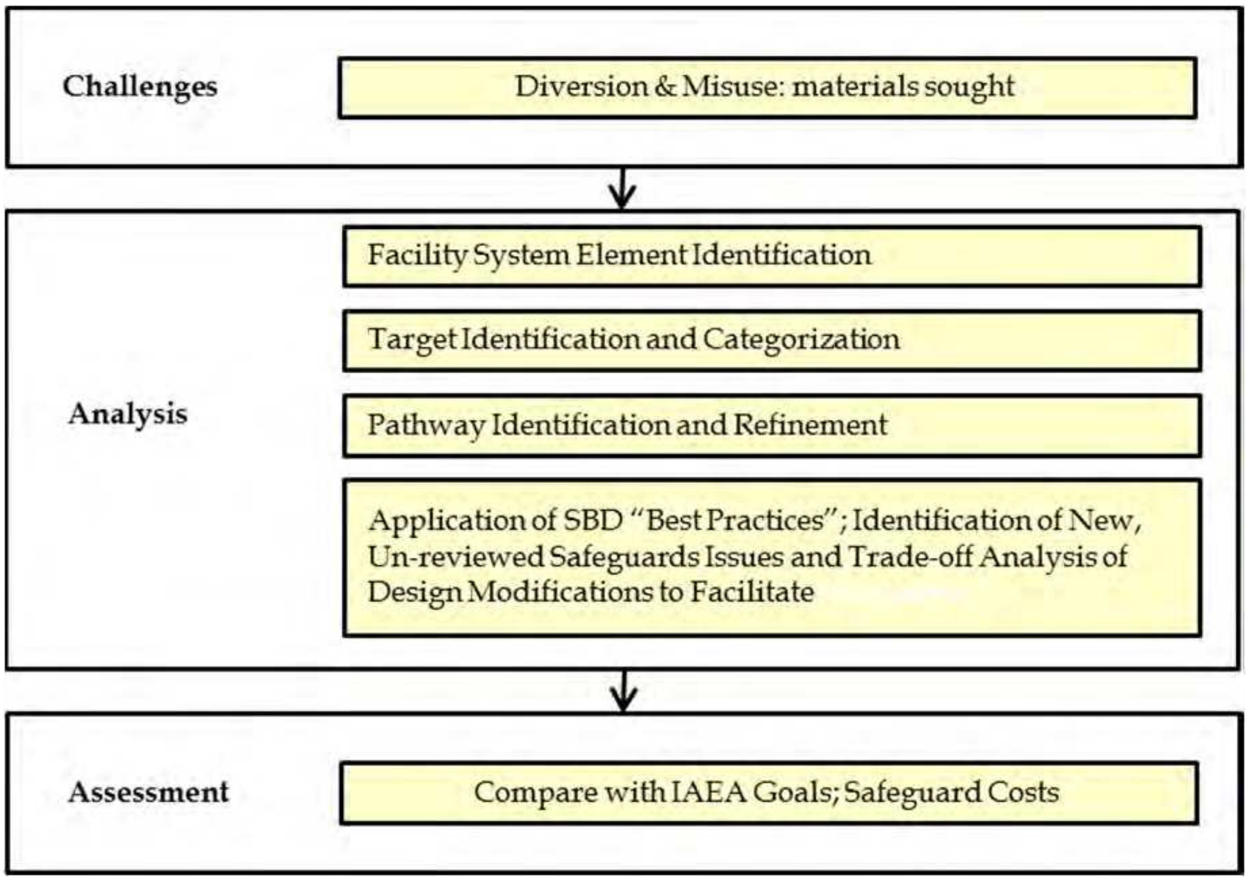

Fig. 4. Safeguards by Design Process (Wonder & Hockert, 2011)

## 7. Conclusion

New approaches for studying proliferation resistance continue to be developed and improved. Their goal is to help ensure that innovative nuclear energy systems are "*unattractive and* [the] *least desirable routes for diversion or development of weapons-usable material.*" The "Safeguards-By-Design" approach has become the subject of intense research because it makes use of safeguardability assessment tools such as proliferation resistance studies to improve the design and construction of new facilities in such a way that they will be easier and more cost efficient to safeguard. Stakeholders and decision makers in the nuclear energy field will need to understand, apply, and advance the concepts discussed here to effectively participate in the development of proliferation resistant nuclear facilities in the future.

Inquiry into the nature of proliferation resistance, the utility of different methodologies to study it, and the extent to which proliferation resistance studies offer useful and meaningful answers and insights for decision-makers continues. A growing body of literature is emerging on these subjects, and will continue to grow over the next several years. A new independent evaluation of proliferation resistance and proliferation resistance methodologies by the United States National Academy of Sciences will begin in the summer of 2011. The result will be a report to the U.S. Department of Energy in 2013 that should be particularly valuable in identifying the strengths and limitations of the concept of proliferation resistance and associated methodologies. Recommendations for whether and what types of additional methodology development activities should follow will be an important result of this work.

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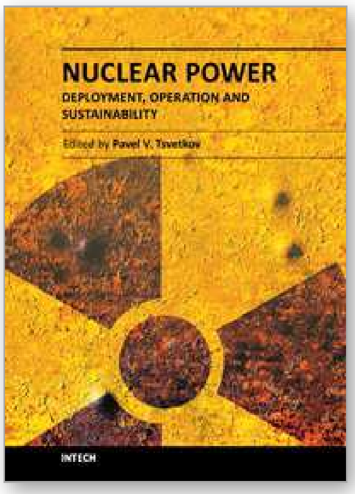

**Nuclear Power - Deployment, Operation and Sustainability**
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We are fortunate to live in incredibly exciting and incredibly challenging time. Energy demands due to economic growth and increasing population must be satisfied in a sustainable manner assuring inherent safety, efficiency and no or minimized environmental impact. These considerations are among the reasons that lead to serious interest in deploying nuclear power as a sustainable energy source. At the same time, catastrophic earthquake and tsunami events in Japan resulted in the nuclear accident that forced us to rethink our approach to nuclear safety, design requirements and facilitated growing interests in advanced nuclear energy systems. This book is one in a series of books on nuclear power published by InTech. It consists of six major sections housing twenty chapters on topics from the key subject areas pertinent to successful development, deployment and operation of nuclear power systems worldwide. The book targets everyone as its potential readership groups - students, researchers and practitioners - who are interested to learn about nuclear power.

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